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Research article

The impact of catchment source group classification on the accuracy of sediment fingerprinting outputs

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ABSTRACT

The objective classification of sediment source groups is at present an under-investigated aspect of source tracing studies, which has the potential to statistically improve discrimination between sediment sources and reduce uncertainty. This paper investigates this potential using three different source group classification schemes.

The first classification scheme was simple surface and subsurface groupings (Scheme 1). The tracer signatures were then used in a two-step cluster analysis to identify the sediment source groupings naturally defined by the tracer signatures (Scheme 2). The cluster source groups were then modified by splitting each one into a surface and subsurface component to suit catchment management goals (Scheme 3). The schemes were tested using artificial mixtures of sediment source samples. Controlled corruptions were made to some of the mixtures to mimic the potential causes of tracer non-conservatism present when using tracers in natural fluvial environments. It was determined how accurately the known proportions of sediment sources in the mixtures were identified after unmixing modelling using the three classification schemes.

The cluster analysis derived source groups (2) significantly increased tracer variability ratios (inter-/intra-source group variability) (up to 2122%, median 194%) compared to the surface and subsurface groupings (1). As a result, the composition of the artificial mixtures was identified an average of 9.8% more accurately on the 0–100% contribution scale. It was found that the cluster groups could be reclassified into a surface and subsurface component (3) with no significant increase in composite uncertainty (a 0.1% increase over Scheme 2). The far smaller effects of simulated tracer non-conservatism for the cluster analysis based schemes (2 and 3) was primarily attributed to the increased inter-group variability producing a far larger sediment source signal that the non-conservatism noise (1). Modified cluster analysis based classification methods have the potential to reduce composite uncertainty significantly in future source tracing studies.

1. Introduction

Sediment fingerprinting has become a key method of determining the importance of the sediment sources in a catchment (e.g. Collins et al., 2010a). However, several methodological uncertainties associated with existing fingerprinting procedures have been highlighted in recent publications (D'Haen et al., 2012; Koiter et al., 2013; Smith and Blake, 2014; Laceby and Olley, 2015; Pulley et al., 2015a & b). Establishing a robust discrimination between sediment sources using suitable tracers is a key recommendation for accurate source tracing (Collins and Walling, 2002), making it a goal of many sediment fingerprinting based studies.

A fairly robust discrimination between different land uses as well as subsurface (i.e. streambank) sources has been established using some tracers. For example, ^{137}Cs or excess ^{210}Pb, where the mixing of tracer fallout through the soil profile during ploughing results in lower activities in cultivated land in comparison to undisturbed grassland or woodland (Walling and Woodward, 1992). Additionally, very low activities would be expected in subsurface sources, which are not exposed to direct fallout (Collins and

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Walling, 2002; Walling, 2004). However, fallout radionuclides (i.e. ^{137}Cs) my not produce ideal source identification in many catchments. For example, robust discrimination might be limited in many catchments if channel banks are composed of displaced surface material or floodplain deposits (with ages >1950's), which has high activities (Such as the floodplain deposits investigated by Owens et al., (1999)). Alternatively, where environmental factors only support shallow channel banks comprising surface soils rather than well-developed vertical faces and processes of diffusion, bioturbation and eluviation cause migration of ^{137}Cs down through the soil profile (Walling and Woodward, 1992; Mabit et al., 2008), or where agricultural rotation between arable crops and short-term ley or untilled grass reduces the distinction between cultivated and undisturbed surface soils (Smith and Blake, 2014). As a result, there is often incomplete discrimination between sediment source using ^{137}Cs, or similarly, excess ^{210}Pb (e.g. Collins et al., 2001; Collins and Walling, 2007; Smith and Blake, 2014). Because of this, it is common practice that ^{137}Cs and many other individual tracers are utilised in a composite fingerprint consisting of many tracers, to help avoid spurious source-sediment matches (e.g. Stanton et al., 1992; Collins et al., 2013). Due to the complex nature of the dynamics of most tracers in the environment, the basis for source discrimination of many of the tracers utilised in composite fingerprints is rarely understood, and instead, a 'black box' type methodology is commonly used, which has been criticised (Koiter et al., 2013; Smith and Blake, 2014).

A review by Haddadchi et al. (2013) shows that it is currently practice to classify sediment source groups by land use (including surface/subsurface sources) in the vast majority of sediment fingerprinting research (Slattery et al., 1995; Walling and Woodward, 1995; Collins et al., 2010a, 2010b; Smith and Blake, 2014). This is despite the fact that the majority of catchments investigated in source tracing studies will contain heterogeneous geology or soil types. For example, Pulley et al. (2015a), Collins et al. (2013), Smith and Blake (2014), Wilkinson et al. (2013), Palazón et al. (2015), Nosrati et al. (2014), Evrard et al. (2013) and Gellis et al. (2009) have all recently published source tracing studies in catchments with heterogeneous geology and/or soil. This potentially represents a problem if the signal of different land use is weakly expressed by the tracers used. Horowitz and Stephens (2008) investigated the impact of land use on the chemistry of river sediment in a large scale study of 51 river basins across the USA, with drainage areas ranging from 28 to 49,800 km^2. It was found that the only land use to have a significant effect on sediment chemistry was urban areas. Therefore, the geochemical signal of land use (and subsurface sources) in river sediments may possibly be very weak. In contrast, the signal of geology or soil type may often be very strong. For example, with the dissolution of magnetic iron oxides which can take place in anoxic and reducing soil conditions (Anderson and Rippey, 1988; Roberts and Turner, 1993), or highly different tracer concentrations in different geological units (Collins et al., 1998; Owens et al., 1999; Pulley et al., 2015c) or spatially variable anthroprogenic tracer inputs (Devereux et al., 2010; Guieu et al., 2010). These factors are likely to result in land use classified source groups with a very large amount of within-group variability. The effect of a large within-source group variability is to significantly increase uncertainty associated with source apportionment results (Small et al., 2002; Collins et al., 2010a,b; Pulley et al., 2015a).

The impacts of tracer non-conservatism caused by factors such as organic matter (Wang et al., 2010; Carr et al., 2010; Nadeu et al., 2011) and particle size (Horowitz and Elrick, 1987; Motha et al., 2003; Pye et al., 2007; Pulley et al., 2015c) may also be increased when a small difference in tracer concentration exists between source groups. For example, if there is only a 10% difference in the mean tracer concentration of two source groups and non-conservatism causes a 5% change to a tracer during sediment transport, very large errors will be present in the final outputs. Alternatively, if a 100% difference exists between tracer signatures in the source groups, a 5% change caused by non-conservatism during sediment mobilisation, intermediate storage and delivery will only have a minor impact on source fingerprinting estimates.

A method which could potentially reduce within-source group variability and increase intra-group variability was developed by Walling et al. (1993) who used pre-selected tracers in a cluster analysis to classify sediment source groups. It was found that land use was the primary controlling factor on tracer signatures and classified 4 to 6 source groups. Walling and Woodward (1995) also used this method and geology was identified as the major factor controlling source group classification. Using this method of source classification provides the benefit that the natural variability in tracer concentrations within a catchment is used to define the source groups; therefore, each source group should have a low within-group variability in tracer concentrations and be substantially different to other groups. Despite these clear advantages, this method of source group classification has largely been neglected in recent literature. It is likely that catchment management goals such as identifying sediment inputs from a specific source such as eroding farm tracks (Collins et al., 2010b) have necessitated the prior selection of source groups without regard to the natural variability in tracers within a catchment.

The overall question this paper aims to answer is: can the objective classification of sediment source groups using an updated cluster analysis based method reduce gross uncertainty in fingerprinting outputs? Additionally, can we modify the cluster analysis derived source groups to suit management goals; in this example discriminating between surface and subsurface sources, while maintaining the benefits of the cluster analysis method.

This study uses artificial mixtures of sediment source samples, some of which are deliberately corrupted by numerous means to test the accuracy of unmixing model results when the different source group classification methods are used. Error evaluation using artificial mixtures has been increasingly adopted as a routine component of sediment source tracing studies (e.g. Palazón et al. (2015).

2. Study area

The sediment source samples were retrieved from the largest tributary sub-catchment (4.3 km^2) of Sywell Reservoir, which is located in the Nene river basin in the East Midlands of the UK. The catchment is composed of Jurassic age mudstones and sand and ironstones in the lower catchment as well as Quaternary diamicton in the upper catchment (Fig. 1). Soils in the catchment are a combination of freely draining brown earths in the lower catchment over the ironstone geology and poorly draining clayey soils in the upper catchment. The land use is predominantly cultivated land (54.4%) used for wheat production with some areas of improved grassland (22.7%) which are used for sheep grazing, as well as woodland (22.7%) (Fig. 1; Morton et al., 2011). The River Nene basin has an average annual rainfall of 638 mm recorded at Althorp over the last 140 years according to records transcribed by the authors from the UK Met Office archives. Construction of Sywell reservoir was completed in 1906, and an area of wetland has developed in alluvial deposits where the river enters the reservoir close to sampling points 1 and 1b (Fig. 1). Very little erosion of toposils was observed in the study catchment, with a single small area of cultivated land appearing to have undergone some minor rill erosion. Channel banks were observed to have slumped and be exposed to fluvial entrainment in many areas. A previously